

नदी घाटी परियोजनाओं में संरचनाओं के लिए
उपकरणों की माप के प्रकारण स्थान का
चुनाव और प्रकार के लिए गाइड
भाग 2 कंक्रीट व मैसेनरी डैम्स
(दूसरा पुनरीक्षण)

**Guide for Types of Measurements for
Structures in River Valley Projects
and Criteria for Choice and Location
of Measuring Instrument**

Part 2 Concrete and Masonry Dams
(Second Revision)

ICS 93.160

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भारतीय मानक ब्यूरो

BUREAU OF INDIAN STANDARDS

मानक भवन, 9 बहादुरशाह ज़फर मार्ग, नई दिल्ली – 110002
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI-110002

www.bis.gov.in www.standardsbis.in

FOREWORD

This Indian Standard (Second Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Hydraulic Structures Instrumentation Sectional Committee had been approved by the Water Resources Division Council.

In the second revision of this standard clause **4.8** and **6.9.1** have been modified.

Dams and related works are built to last many decades, and form key structures to the development of river basin, potential for irrigation, water supply, flood control, navigation, recreation and power generation.

Inherent in the reservoir water storage are tremendous forces which the dam is expected to withstand throughout its operational life. Consideration of the disastrous effect of the failure of a dam in terms of loss of life and property and the negation of planned benefits of the project, make it imperative that means should be available in the dam for providing information on continued assurance of its safety.

The extent of internal distress in a dam cannot always be directly measured. However, diagnostic procedures are available which can help in identifying most ailments. Key to these procedures is effective instrumentation, which is a vital part of dam design. Instruments strategically implanted in the vital zone scan provide meaningful clues.

The objectives of instrumentation are manifold. The instruments embedded in, or installed at the surface of dams and other hydraulic structures keep a constant watch over their performance in service and indicate the distress spots which call for remedial measures. Thus these instruments play an important role in checking the safety of the structure.

Observations from the instruments form a cumulative record of the structural behaviour. The study of structural behaviour provides an important aid in modifying purely theoretical treatment so as to include the effect of actual field conditions. Most hydraulic structures are built on rather conservative assumptions to provide for the ‘unknowns’ in the design. Observations from the instrumentation help reduce these ‘unknowns’ and place the future designs on sounder footings. The information obtained through measurements promotes the understanding of the influence of various parameters on the structural behaviour and leads to formulations of more realistic design criteria.

Various new or modified construction techniques like rolled concrete construction are being evolved. However, these techniques are not accepted by the engineers till their long term performance is proved. The observations from instruments help to evaluate the suitability or otherwise of the new modified techniques.

Many dams, particularly older ones, are modified to allow for increased capacity, increased safety or on account of some efficiency noted. Instrumentation readings, available before and after the modifications, will help to clarify and indicate whether the remedial actions were effective or otherwise.

The condition of dam and its overall safety has to be checked regularly not merely to satisfy the engineer community but also to demonstrate to the public at large that the dam is safe performing in accordance with the design assumptions.

Masonry is a heterogeneous material and there is very little experience of instrumentation in it. Further, properties, such as creep, compressive, flexural or tensile strengths, modulus of elasticity, and thermal properties cannot be easily ascertained in the case of masonry dam construction. The instrumentation has, therefore, limitations as far as masonry dams are concerned. However, as experience of instrumentation in masonry dams is gained, better idea can be had regarding the use and utility of instrumentation in masonry dams.

This standard was first published in 1976. The revision of the standard has been taken up to incorporate certain changes found necessary.

In the formulation of this standard due weightage has been given to international co-ordination among the standards and practice prevailing in different countries in addition to relating it to the practices in the field in this country.

For the purpose of deciding whether a particular requirement of this standard is complied with the final value, observed or calculated expressing the result of test or analysis shall be rounded off in accordance with IS 2 : 1960 ‘Rules for rounding off numerical values (*revised*)’. The number of significant place retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

GUIDE FOR TYPES OF MEASUREMENTS FOR STRUCTURES IN RIVER VALLEY PROJECTS AND CRITERIA FOR CHOICE AND LOCATION OF MEASURING INSTRUMENT

PART 2 CONCRETE AND MASONRY DAMS

(Second Revision)

1 SCOPE

This standard (Part 2) lays down the types of measurements need to be done in concrete dams and masonry dams in river valley projects. Criteria for choice and location of the required measuring instruments are also given.

NOTE — Details of specifications, instrumentation, maintenance and observation of individual instruments will be covered by separate codes.

2 REFERENCES

The standards listed below contain provisions which, through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards listed below:

<i>IS No.</i>	<i>Title</i>
4967 : 1968	Recommendations for seismic instrumentation for river valley projects
5225 : 1992	Meteorology — Raingauge, non-recording (<i>first revision</i>)
5235 : 1992	Meteorology — Raingauges, recording specification
6524 : 1972	Code of practice for installation and observation of instruments for temperature measurement inside dams — Resistance type thermometers
8282	Code of practice for installation, maintenance and observation of pore pressure
(Part 1) : 1976	Measuring devices in concrete and masonry dams: Electrical resistance type cell

<i>IS No.</i>	<i>Title</i>
(Part 2) : 1996	Vibrating wire type cell
13073 (Part 1) : 2002	Code of practice for installation, maintenance and observation of displacement measuring devices for concrete and masonry dams: Part 1 Deflection measurement using plumb line
13232 : 1992	Code of practice for installation, maintenance and observation of electrical strain measuring device in concrete dams

3 OBLIGATORY AND OPTIONAL MEASUREMENTS

No general rule can be given for the type of measurements to be made at dams as they are of many kinds, have different site conditions and have different problems. Even then some kinds of measurements are obligatory for all concrete dams while others are optional.

3.1 Obligatory Measurements

The following measurements are obligatory for all dams:

- a) Uplift pressure at the base of the dam at a sufficient number of transverse sections;
- b) Seepage into the dam and appearing downstream therefrom;
- c) Temperature of the interior of the dam; and
- d) Displacement measurements. Except for very small structures.

Displacement measurements should include one or more of the following types of measurements:

- a) Those determined by suspended plumblines;
- b) Those determined by geodetic measurements where warranted by the importance of the structure; and

- c) Those determined by embedded resistance joint meters at contraction joints where grouting is required to be done.

3.2 Optional Measurements

The following measurements are optional and may be undertaken where warranted by special circumstances of project. These would be beneficial for high dams, structures of unusual design, structures where unusual or doubtful foundations exist, the verification of design criteria and for effecting improvement in future designs:

- a) Stress,
- b) Strain,
- c) Pore pressure (as distinct from uplift pressure), and
- d) Seismicity of the area and dynamic characteristic of the structure.

Due to ever increasing demand of power, emphasis has been laid to construct large size of hydroelectric project with very high dam. With the present trend, dam sites are neither geologically ideal nor seismically suitable as most of the best sites have already been considered for the purpose. Due to this reason those measurements that were considered optional at the time of framing this code may become obligatory now for high dams especially in the Himalayan region.

4 TYPES OF MEASUREMENTS

4.1 Measurement of Uplift Pressure

It is important to determine the magnitude of any hydraulic pressure at the base of a dam. The effect of uplift on a dam is to reduce its effective weight on account of resulting buoyancy.

4.2 Measurement of Seepage

4.2.1 Seepage is undoubtedly the best indicator of the overall performance of a dam because this reflects the performance of entire dam and not just the condition at discrete instrumented points. Any sudden change in the quantity of seepage without apparent cause, such as corresponding change in the reservoir level or a heavy rain fall, could indicate a seepage problem. Similarly, when the seepage water becomes cloudy or discoloured contains increased quantities of sediment, or changes radically in chemical content, a likely serious seepage problem is indicated.

4.2.2 It is customary to provide grout curtain near the upstream face of the dam. Besides, a drainage curtain in the foundation and porous drain in the body of the dam are provided to intercept any seepage that passes through the grout curtain and through the body of the dam respectively. Measurement of seepage water along with uplift measurement at the plane of contact of the dam and its foundation will give direct indication of the effectiveness of the grout curtain and drainage curtain

and will indicate whether any remedial measures are necessary. The chemical analysis of the seepage water through the foundation drainage system will help in assessing whether any foundation material is being washed out.

4.2.3 Likewise the quantum of water passing through ungrouted contraction joints or cracks would indicate about the workmanship in general as also any damage that might have been caused to the seals in the contraction joints. The chemical analysis of the water in case of masonry dam may be indicative of any possible leaching action on mortar used in the construction of the masonry dam. Corrective measures such as grouting of dam and foundation, besides improving existing drainage or providing additional drainage could thus be planned.

4.2.4 Wet spots or seepage appearing at new or unplanned locations at the abutments or downstream of a dam could also indicate a seepage problem. Measurement of seepage downstream of the grout curtain provides a direct indication of the adequacy and effectiveness of the grout curtain, drainage curtain and functioning of the drains and holes to decide when and where remedial measures may be required.

4.3 Measurement of Temperature

4.3.1 Measurement of Temperature During Construction

For concrete gravity dams it is very important to know the thermic variations in the dam during its construction which enables to determine whether the concrete setting process is normal or otherwise to achieve this purpose, temperature measuring devices are embedded within the dam body and also mounted on the surface according to a predetermined plan for useful observations. Any abnormal setting process indicated by temperature observations may lead to a change in the concrete lift height, and also changes in the treatment of aggregates before concreting and of the mass concrete during curing.

4.3.2 Measurement of Temperature of the Dam Interior

It is necessary to measure temperature in the body of concrete and masonry dams in order to ascertain the nature and extent of thermal stresses and the consequent structural behaviour of the dam and also to ascertain when to undertake grouting of contraction joints that may have been provided for the structure.

4.3.3 Measurement of Temperature of Reservoir Water and Air

Measurement of temperature of reservoir water and air is essential for distinguishing the effects of ambient and water temperatures on such measurements as deflection, stresses, strains and joint movement sand settlements.

4.4 Measurement of Displacement

Measurement of displacement of points either between two monoliths, or between foundation and body of the dam or the displacement of any joint of the dam with respect to the surrounding area will immediately reveal any distress conditions developing in the dam. Measurement of displacement is thus one of the most important factors to be studied while observing the structural behaviour of a dam.

4.4.1 Internal Joint Movement

Concrete and masonry dams are generally built in blocks separated by transverse joints. It is essential to know whether, there is any relative movement between two blocks. The movement is likely to be due to differential foundation behaviour. Further, the relative movement of blocks is important from the point of view of grouting of transverse contraction joints.

4.4.2 Surface Joint Movement

Measurement of joint movement at the surface of the locations accessible from galleries is made by detachable gauges with a view to assess the amount of joint opening of two blocks of the dam. These gauges may also be advantageously used for observation of opening or of closing of surface cracks at any location.

4.4.3 Foundation Displacement

Measurement of vertical or horizontal displacement of foundation provides information for taking preventive measures for inclination, distortion etc. of structures. The data can also be used for studying the elastic and inelastic properties of dam and foundation. Measurement of foundation displacement involves vertical and horizontal displacement of part of foundation with respect to dam.

4.4.4 Displacement of One Part of the Dam Relative to other Parts of the Dam

Measurement of relative displacement of two points in a dam is a direct indication of structural behaviour of the dam. The deflection characteristics of a dam observed for the first few years will reveal any dangerous tilt or movement of the dam. These observations are made by regular and inverted plumb lines. The plumb line data together with other supporting data may be used to study the elastic behaviour of the dam.

4.4.5 Displacement of Dam with Reference to Surrounding Area

This measurement gives the absolute displacement of the dam with respect to surrounding area, and is a direct indication of structural behaviour of the dam.

Provisions would be made for periodic deflection measurements. Where topography permits, this can be done by theodolite from fixed bases, using either line-of-sight over the top of the dam or by turning angles

to targets on the downstream face and at the crest. At concrete dams, the deflections should be consistent with changes in reservoir water surface level and in temperature and should not change appreciably from year to year.

4.4.6 Measurement of Tilt

Tilt is measurement of rotation in vertical plane. It is normally measured with the help of tilt meter system consisting of tilt meter sensor, tilt plates and indicator. Tilt plates are bonded to the surface of mass of structure under observation. The sensor is oriented on three pegs of tilt plate and senses change in tilt of tiltplate. The portable indicator gives the degree of rotation.

4.5 Measurement of Stress

Direct measurement of stress developed inside the mass of concrete or masonry helps in watching the structural behaviour of dams and their foundations. Any adverse change in stress will indicate distress conditions and remedial measures can be taken. The observation of stress also helps in studying the assumed stresses and actual stresses in dams and this can be used in improving upon the design procedure.

4.6 Measurement of Strain

Factors like temperature, chemical action, moisture change and stress result in volume changes, which cause strain in the structure. The measurement of strain, therefore, becomes necessary. As the design of structures is based on stress it is essential to measure the stresses developed in the structures during its life time. Moreover, the instruments available for measurement of stresses can measure only compressive stress and not the tensile stress. Further, the stress measuring instruments are more expensive and delicate than strainmeters and hence, it is a common practice to measure the strain and to calculate from it the developed stress.

4.7 Measurement of Pore Pressure

4.7.1 Since large concrete and masonry dams are provided with internal formed drains located near the upstream face, a record of pore pressure development and its variations would indicate the effectiveness and adequacy of these drains. Any sudden unusual increase in the pore pressures will be indicative of choking up of these internal drains and any unusual reduction from the normal would indicate possibility of formation of cracks or establishment of flow channels in the body of the dam.

4.7.2 Measurement of uplift in the foundation is mandatory for all gravity dams and is generally accomplished by uplift pressure pipes which provide direct indication of the prevailing magnitude of uplift resulting from the operating reservoir heads and consequently the effectiveness of the grout curtain

close to the upstream face of the dam and effectiveness of the drainage curtain provided in the foundation apart from checking of design assumptions for its stability.

4.8 Seismicity of the Area and Dynamic Characteristic of the Structure

Surveillance of seismic environment of the project site needs special attention in case of large dams to know about the seismicity of the region before taking up construction. Creation of a reservoir generates additional load on the surrounding area and underlying geological strata. Thus, it becomes essential to know the change in the seismicity pattern, if any, due to creation of large reservoir. The behaviour of dam during an earthquake also needs to be assessed. A seismological laboratory may be established near the project site for evaluation of seismic parameters for large dams located in seismic zone III, zone IV and zone V.

4.9 Measurement of Water Level on Upstream and Downstream Side

This measurement is useful for calculating the water pressure on the upstream face and downstream face of the dam.

4.10 Other Measurements

The following other measurements which would aid in interpretation of the main instrumentation data are also necessary.

4.10.1 Rainfall Measurement

Rainfall measurement is routinely carried out as part of hydrological observation.

4.10.2 Wave Height and Ice Effect

Measurement of height of wave and effect of ice are also useful for interpretation of results of structural behaviour of the dam.

4.10.3 Measurement of Level of Silt Deposit at the Upstream Face of the Dam

This would be useful for determining the pressure due to silt deposit on the upstream face of the dam.

4.10.4 Other Meteorological Measurements

Other meteorological measurements such as of wind velocity and wet and dry bulb temperatures may also be made.

5 AUXILIARY DATA TO BE COLLECTED

5.1 Data to be Kept of Construction/Operation Stages

The following data of construction/operation stage should be kept:

- a) Concrete or masonry placing diagram, showing lift placement date, placing temperature and lift thickness, type of method and duration of curing;

- b) Cooling arrangements, if any, and their details;
- c) Final rock elevations and unusual geological features; and
- d) Record of joint grouting operations.

5.2 Data to be Kept from Control Operations

The following data of control operations should be kept:

- a) Cement content, water-cement ratios, aggregate grading, amount of entrained air, and admixtures used, if any;
- b) Physical and chemical properties of cement including heat of hydration;
- c) Chemical and physical properties of aggregates; and
- d) Maximum and minimum air temperatures.

5.3 Laboratory Data

The following laboratory data should be collected:

- a) Specific heat, conductivity, diffusivity, thermal coefficient of expansion dynamic and static modulus of elasticity, creep, compressive, flexural and tensile strengths of concrete;
- b) Similar properties for masonry to the extent;
- c) Specific surface of cement used for joint grouting and properties of pozzolana, if used; and
- d) Data of water samples.

6 CHOICE OF INSTRUMENTS AND LOCATION OF MEASURING INSTRUMENTS

Instrumentation should be provided in at least one deepest over flow block and two abutment blocks. It should also be indicated that the number of instrumented blocks may be increased with the increase in length of dam.

6.1 General

6.1.1 Instruments presently available are designed on four basic principles namely, mechanical, hydraulic, pneumatic and electrical. Electrical type instruments include unbounded resistance type and vibrating wire. Out of the four types of instruments mechanical, pneumatic and hydraulic type of instruments are simple, rugged, reliable, cheaper and easy to operate, but have lower response and lower accuracy. The mechanical type cannot be read remotely while pneumatic and hydraulic though can be read remotely, have problems with connecting tubes of blocking and breaking. Whereas electrical type of instruments facilitates easy remote reading, use of data logger and computers apart from their high sensitivity, high resolutions and accuracy.

6.1.2 Bonded strain gauge type of instruments should not be used for embedded applications. In special

applications where the other types of instruments have limitations namely, dynamic measurements, these may be used only on surface and accessible locations and for short term observations. The unbonded resistance wire type and vibrating wire type of instruments have long term stability and are in use extensively. The main disadvantages with the bonded strain gauge types are that they suffer from drift due to creep in bonding material and backing material, variation in cable conductor resistance due to temperature, leakage resistances between cable conductors due to moisture ingress. Thus they are unsuitable for long term application. The unbonded resistance wire type instruments also suffer from the influence of change in cable conductor resistance and leakage resistance between conductor due to temperature changes and moisture ingress respectively. However the effect can be minimized and temperature corrections applied.

6.1.3 Vibrating wire type instruments are not sensitive to cable resistance and moisture movement. They are under influence of temperature changes but the effect is less significant. They are either supplied with the moistures or correction factor by the manufacturer to compensate the effect.

6.1.4 There is no simple rule which can determine the number of instruments, their exact type or location. Their determination remaining primarily a matter of experienced judgement.

6.1.5 The number of devices installed in a dam is less important than the selection of proper types of instruments, their location and intelligent interpretation of the data.

6.1.6 The quality of instruments should be of paramount importance since these are expected to work for very long periods, say 25 - 30 years. More importantly so because embedded instruments cannot be retrieved and repaired if these become defective.

6.1.7 In a selection of equipment, service requirements must be carefully weighed. An instrument of rugged construction that gives reasonably accurate results may be preferable to a more precise but delicate instrument.

6.1.8 Ideally, the instruments selected for a given situation should have the following characteristics:

- a) It should be sufficiently accurate;
- b) It should have long term reliability and stability;
- c) It should have low maintenance requirements;
- d) It should be compatible with construction techniques;
- e) It should have low cost; and
- f) It should be simple but rugged.

6.2 Uplift Measuring Instruments

Instruments which may be used for measurement of uplift are uplift pressure pipes.

6.2.1 Measurement of Uplift

The device for measuring uplift consists of a pipe installed at the point where uplift pressure is to be measured, such that it terminates in a gallery directly above the measuring point which is generally 1 m below the base of a dam.

6.2.2 The pipes placed upstream of the grout curtain are usually inclined towards upstream face fitted with a tee section and a Bourdon type pressure gauge for observing water pressure and those placed downstream of the grout curtain are read by sounding or with pressure gauge. Last pipe is generally inclined towards downstream to cover maximum width of the dam.

6.2.3 Uplift pressure pipes are the simplest and most rugged. Only difficulty encountered in case of these pipes is when they get choked. Restoration of choked pipes is possible by drilling a hole through the pipe but if there is a bend in the pipe, drilling is not possible and the pipe has to be abandoned.

6.2.4 Uplift pressure measurements should be made at cross sections representing the principal types of foundation strata. Uplift measurements should be done at least at three cross sections in case of small dams and at least at five cross sections in the case of large dams. The cross sections chosen should include one of the deepest overflow and non-overflow sections, and some sections near the abutments. Uplift measuring points on a cross section line should be located taking into consideration the geological features appearing at the cross section so that the effect of such geological features on the uplift pressure could be evaluated. At any cross section, uplift measurements should be done at:

- a) upstream of the groutline;
- b) between the grout line and the drainage hole;
- c) immediately after the drainage hole; and
- d) at the end of the cross gallery.

Spacing between (c) and (d) may be divided equally. In case of large base widths a spacing of 20m may be adopted.

6.2.5 Uplift pressure cells based on vibrating wire or unbonded resistance wire principle should be used for remote indication applications.

6.3 Seepage Measuring Instrument

Small notches and weirs may be constructed at points where seepage is to be measured from the water level readings at these points quantity of seepage can be computed. Where any drainage hole shows abnormal

flow (quantity and pressure) a regular program of observations of pressure and quantity of seepage may be necessary. Float operated water level sensors using vibrating wire load cell is one type instrument that should be used for remote indication.

6.4 Temperature Measuring Instruments

6.4.1 Temperature measurement can be done by either:

- a) Resistance thermometers, or
- b) Vibrating wire type thermometers.

6.4.2 The resistance thermometer works on the principle that, resistance of an electrical wire is a function of temperature. The vibrating wire type works on the principle that, a change in length of vibrating wire results in proportional change in natural frequency.

Resistance type thermometers are accurate yet comparatively less costly and hence, are extensively used.

6.4.3 As temperature is one of the major factors causing stresses it is necessary to measure it at many places in the dam. A typical scheme for location of thermometers would be to place them in 1.5×15 mg rid horizontally and vertically in a minimum of one block in the spillway portion of the dam and in other portions depending upon the data required for detailed study of the structural behaviour of the dam. A few thermometers should be placed near and on the downstream face to evaluate the rapidly fluctuations in the temperature. Thermometers placed on upstream face as a continuation of the main thermometer grid will serve to evaluate lake temperatures close to the dam. For measurement of foundation temperature, thermometers should be placed near the base of the dam and also in holes drilled in the foundations at desired locations (*see also IS 6524*). As unbonded resistance wire type stress, strain and joint meters measure temperature accurately, it is not necessary to install thermometers at their locations. For details *see IS 6524*.

6.5 Displacement Measurement Instruments

6.5.1 Internal Joint Movement

Two types of joint meters are available, namely:

- a) Unbonded resistance wire type, and
- b) Vibrating wire type.

In the case of large dams joint meters should be provided in at least three blocks, deepest central block and a block each in the abutment portion. In plan of a given elevation the joint meters in each of these blocks should be installed on the centre of the longitudinal joints and at the centre of the transverse dimensions of the monoliths in the block, spaced about 15 m vertically for the entire heights of the longitudinal and transverse joints. This spacing may be modified in the top portion of the joint if joint height does not permit of 15 m spacing for the entire height.

6.5.2 Surface Joint Movement

Surface joint measurements are made either on the surface or at locations accessible from galleries.

The measurements are made by calibrated tapes by fixing two reference points one each on either side of the joint and by accurately measuring the distance between the two points at certain intervals. This discloses the amount of joint opening.

6.5.2.1 Portable gauges with dial indicators are most common mechanical gauges for measurement of surface movements. Scratch gauges are occasionally used.

6.5.2.2 These measurements should be taken at locations corresponding to embedded joint meters so that results can be compared. The surface joint measurements are also taken where surface cracks are noticed.

6.5.3 Foundation Displacement

6.5.3.1 Foundation displacement can either be vertical or horizontal.

6.5.3.2 Vertical foundation displacement is measured through a bore hole drilled in the foundation from the foundation gallery by anchoring one end of a thin galvanized wire rope at lower end of the bore hole and providing a plumb bob to the other end taken over a pulley. Foundation movement thus can be measured in terms of displacement of the bob. The plumb bob over a pulley arrangement can be replaced by electrical devices like unbonded strain gauge, vibrating wire strain gauge, LVDT or a potentiometer. For the electrical type devices except potentiometer the wire rope can be replaced by a series of interconnectable rods. The instrument is known as bore hole extensometer.

6.5.3.3 The measurements should be taken at all points where foundation deformation is expected to be significant. It is preferable to have one measurement each in a grid of 30×30 m.

6.5.3.4 The vertical displacement of foundation can also be ascertained by installing joint meters between the contact of the foundation and the dam. The end fixed in the foundation can be mounted on a pipe with its lower end anchored at the bottom of a drilled hole.

6.5.3.5 Horizontal foundation displacement can be measured by inverted plumb line. Inverted plumb line consists of a wire; the lower end of which is anchored in the foundation while the upper end is attached to a float, buoyed up by water in a covered tank. The displacement of the wire is measured by a co-ordscope or microscope and micrometer slide. The inverted plumb line should be installed in the same block in which normal plumb line is installed so that results can be used together.

6.5.4 Displacement of Dam by Plumb Line

6.5.4.1 A plumb line consists of a wire, suspended through a shaft in the dam, the upper end of the wire being anchored to the body of the dam and the lower end carrying a heavy weight. The oscillations of the plumb line are damped by immersing the plumb weight in oil.

6.5.4.2 The deflection of the wire is measured with reference to a reference point. The displacement of wire is measured by a co-ordimeter and co-ordiscope or microscope and micrometer slide.

6.5.4.3 One plumb line is installed at the deepest central section and also one each on either side at quarter points of the dam. If the height of the dam does not change much one plumb line can be installed each at one-third the length of the dam.

6.5.5 Displacement of Dam with Reference to Surrounding Area

6.5.5.1 This measurement is done by surveying methods, namely, either by geodetic method or collimation method.

6.5.5.2 In the geodetic method two piers are constructed one on each bank and also on the downstream side of the dam. The piers are used for accurately locating the theodolite for angular measurements. Targets are fixed on the downstream face of the dam and accurate measurements of movements of these targets are made from the two piers with precision instruments. Theodolite stations should be connected to an orientation point outside the influence of the dam and shift of the theodolite stations accounted for in the computations.

6.5.5.3 The geodetic method has the advantage of measuring absolute displacement very accurately but involves complicated calculations.

6.5.5.4 Targets should preferably be fixed on grid pattern at locations which detail the horizontal and vertical elements of the structure as adopted for theoretical analysis. Targets should also be located in the blocks containing the plumb line so that the displacements by the two methods can be compared. The actual results of displacement can then be compared with analytical results.

6.5.5.5 In the collimation method, a line of sight is established which remains fixed during the life of the structure. The movement of points on the dam crest are then measured with reference to the line of sight. Collimeter is used for establishing the line of sight. Targets for the observation should preferably be fixed on each block.

6.5.6 Measurement of Tilt

Tilt is measurement of rotation in vertical plane. It is normally measured with the help of tiltmeter system consisting of tiltmeter sensor tilt plates and indicator.

Tiltplates are bonded to the surface of mass of structure under observation. The sensor is oriented on the three pegs of the tiltplate and sense change in the tilt of tiltplate. The portable indicator gives the degree of rotation.

6.5.6.1 The instrument consists of a base which is permanently fixed in the concrete and a clinometer which is placed on the base. The clinometer is properly placed on the base and air bubble is centered with the help of a micrometer screw. The reading of the micrometer screw obtained at any particular line of observation when referred to the initial reading gives the value of tilt.

6.5.6.2 Tilt measurements are also made by vibrating wire clinometers. Vibrating wire type clinometers are either surface mounted or embedded in the body of dam. A cylindrical core houses a special pendulum surrounded by damping oil. A vibrating wire is stretched between the pendulum and the core. The instrument works on the principle that any change in the position of pendulum will change the tension in the vibrating wire and its frequency of vibration will change.

6.5.6.3 Tilt measurements should preferably be made where plumb line observations are made so that results can be compared and used together. For details IS 13073 (Part 1) may be referred to.

6.6 Stress Measuring Instruments

6.6.1 One of the stress meters commonly used consists of mercury filled diaphragm to which is attached a measuring unit consisting of unbonded resistance wire strain meter. The stress applied to the mercury filled diaphragm is converted into strain by elastic deformation of diaphragm and is measured by the strain meter. The meter is useful only for the measurement of compressive stress and cannot be used for tensile stress measurement.

6.6.2 Stressmeter is located only in zones subjected to compression. As the maximum stresses are developed near the foundation both in reservoir full and empty conditions and at a location where height of the dam is maximum, the stress meters should be located in the monolith of maximum height. There should be at least 5 stress meters in a straight line from upstream face to downstream face and in the horizontal plane. Stresses may also be measured at special locations where high stresses are anticipated or where special information is desired. Stress meters could also be used

on the upstream face of the dam for the determination of pressure exerted by silt.

6.7 Strain Measuring Instruments

6.7.1 Strain meters can be generally divided into two classes, namely:

- a) Meters which can be used on surface and at accessible location; and
- b) Meters that can be embedded into the body of the structure. Surface strain measuring devices are useful for superficial and short term strain measurements. Embedded type instruments are useful for long term strain measurements for finding out the structural behaviour of dams.

6.7.2 Meters which can be Used on Surface and Accessible Locations

The meters of the first class consists of a sensitive dial gauge and by some arrangement the dial gauge measures the change in distance between two fixed points on the surface. The magnification of displacement between the two points is obtained by mechanical and optical means. Bonded wire, unbonded wire and semiconductor gauges are used for special applications only.

6.7.3 Embedded Type Meters

The only stable strain meters that have embedment applications are the unbonded resistance wire type and the vibrating wire type. The former works on the principle that the electrical resistance of the wire changes with the strain applied while in the latter the frequency of vibration of the wire changes with the strain applied.

In the determination of the strains at a particular point in a massive structure several choices of placing the instrument may be made, such as:

- a) *One strain meter* — This will provide strain history in one direction at the point without checking;
- b) *Duplicate strain meters on one axis* — This still provides information on only one axis but gives the reassurance of checking; and
- c) *Five strain meters* — Four 45° apart in the plane of interest and one normal to the plane. Principal strains can thus be calculated from data furnished by a group of strain meters.

6.7.3.1 In addition to the set of strain meters indicated in **6.7.3 (c)**, one ‘no stress’ strain meter is required to be installed by the side in conjunction with strain meter groups to determine the corrections to be applied on account of creep, autogenous growth and thermal expansion of mass concrete. This is accomplished by embedding an ordinary strain meter in a typical mass concrete which is isolated from deformation due to loading but is responsive to the temperature, moisture and growth changes prevailing in the mass concrete

of the structure. If a check is desired, another set of 5 strain meters as indicated in **6.7.3 (c)** may be installed.

6.7.3.2 In the case of masonry dams, along with normal strain gauge meters, it is recommended that long gauge strain meters using unbonded resistance wire strain meters or joint meters or vibrating wire type long basis extensometers may be provided in a group side by side. This is called no stress strain meter. ‘No stress’ strain meter embedded by the side of each group should be ordinary unbonded resistance wire or vibrating wire type strain meter.

6.7.3.3 It is necessary to have at least five strainmeter locations in a straight line from upstream face to downstream face and in one horizontal plane. The strain meters should be near the foundation level as stresses are maximum there.

6.7.3.4 Stress meters and strain meters are generally installed side by side so that results of both the observations can be used together. Stress and strain meters may be installed at any location where development and observation of stress is of interest.

For details IS 13232 may be referred to.

6.8 Pore Pressure Measuring Instruments

6.8.1 The device for measuring pore pressure could be hydraulic, pneumatic or electrical type.

6.8.2 The electrical pore pressure cell (Piezometer) is either of the unbonded resistance wire type or vibrating wire type. Detailed information on them would be available in IS 8282(Part 1) and IS 8282 (Part 2).

6.8.3 Installation of pore pressure meter is a precise job and should be carried out with great care. In concrete and masonry dams, these meters may be installed normally at 10 to 15 m spacing along the width of the dam. The bottom row of pore pressure meters may be located either at the contact plane of foundation and concrete, or just above the foundation or in the foundation by drilling holes as may be required by the design. A second row may be installed at one-third or half the height of the dam. For details IS 8282 (Part 1) and IS 8282 (Part 2) may be referred to.

6.9 Earthquake Measurements

6.9.1 As per recommendations of IS 4967, a seismological observatory for the entire project is to be established at the project site for evaluation of seismic parameters for large dams located in seismic Zone III, Zone IV and Zone V. The location of observatory should be so selected that the firm rock or suitable ground is available for founding the instrument pillars. The observatory may preferably be located at site which is unaffected by vibrations caused by power house operations, etc.

6.9.2 The strong motion accelerographs and structural response recorders should be installed in the dam at the base (in a recess provided in the foundation gallery and at the top of the dam. If the height of the dam exceeds 100 m, these may also be installed near the mid-height of the dam. The location may be suitably selected to avoid the background seismic noise created due to the vibration originating from the appurtenant works of the dam. The instruments located in the foundation gallery are meant for observing the input ground motion in the event of major earthquake. The instruments located at the top of the dam are expected to provide information about response of the structure to the earthquake.

6.10 Water Level Measurements

Automatic water level recorders are installed on the reservoir to record the water level fluctuations. The measurement of water level is essential for establishing relation between the water level variations and the structural parameter variations being monitored. The water level measurement is a routine measurement as a part of hydrological observations for the dam project.

6.11 Other Measurements

6.11.1 Rain Fall

Rainfall measurement is also a routine measurement as part of hydrological observations. Raingauges ordinary or self-recording type are normally installed at each dam site, however, use of advanced type rain gauges such as tipping bucket are not ruled out from use but are recommended being more accurate (see IS 5225 and IS 5235).

6.11.2 Wave Height

Wave height can be measured by installing wave height recorder. The wave height information is important to assess free board of the dam.

6.12 A simple, portable, battery operated read out unit with 4-digit LCD display should be used. Calibration data for each transducer should be provided when a simple read out unit to read frequency is used, for converting the frequency readings of relevant engineering units.

Read out units with facility to read the relevant engineering units directly on the display can be used in place of the frequency readout units.

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This Indian Standard has been developed from Doc No.: WRD 16 (10907).

Amendments Issued Since Publication

Amend No.	Date of Issue	Text Affected

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